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December 8, 1966

Contracting Officer
Post Office Box 6788
Fort Davis Station
Washington, D.C. 20020

Attention: [redacted]

Dear Sir:

We are pleased to submit this proposal in response to your RFP # RD-5-67 dated October 27, 1966.

Our proposal package consists of 1) this letter of transmittal, 2) our technical proposal and 3) a cost breakdown.

25X1A The cost to perform the proposed effort on a cost-plus-fixed-fee basis i[redacted] which includes a fixed fee of [redacted] Delivery 25X11
of the final report will be made not later than 12 months after receipt of authorization to proceed.

It is contemplated that any contract resulting from this proposal will contain terms and conditions compatible with a cost-plus-fixed-fee type contract. Our proposal is valid for a period of ninety (90) days after which we reserve the right to revise it due to changed conditions. No royalties are contemplated in connection with this procurement.

Should additional information be required please do not hesitate to contact me.

[redacted] 25X1

25X1

Manager, Contracts Administrator

cc: 3 copies to

25X1 [redacted]
Post Office Box 8031
Southwest Station
Washington, D.C. 20024

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CONTENTS

1. SUMMARY

25X1 [redacted] proposes to investigate what is believed to be a unique technique for the identification of crop species and the estimation of crop vigor and potential yield. These techniques involve the correlation of visual photointerpretive data with quantitative data acquired by microdensitometric measurement of aerial photographs.

This proposal is based on tests conducted by [redacted] that indicate that 25X1 different crops are imaged on aerial photography in such a manner that microdensitometric traces produce unique and recognizable signatures. It is expected that further research will reveal that unique signatures will enable a trained photointerpreter to establish the identity and health of the crop at any particular time, and to estimate the probable yield of the crop at harvest, from a correlation of photointerpretative and densitometric data.

25X1 [redacted] proposes to perform this research by obtaining photointerpretative and densitometric data from photographs of crops on which ground data are known. If the concepts explained in this proposal give evidence of feasibility, 25X1 [redacted] will apply the findings of the initial research to photographs of crops on which ground truth data are available, but which will not be examined until the interpretation has been completed. If, as is expected, the techniques described herein correlate with the ground data on crop species, health, and yield, 25X1 [redacted] will extend the research to actual or simulated hyperaltitude photography of domestic areas, and will attempt to show that keys and other reference materials can be compiled that will enable a trained photointerpreter to make the required estimates and identifications without recourse to ground data.

2. INTRODUCTION

2.1 STATE OF THE ART

2.1.1 The estimation of crop health and potential yield by interpretation of aerial photographs is not a new concept. A high degree of accuracy has been achieved in deriving such data from large scale, high resolution photography of various crops. Much of the work done to date has been with photos made on panchromatic black-and-white photography. [redacted] 25X1

25X1 [redacted]

2.1.2 Routine photointerpretation techniques have been used for most of this work. That is, interpreters have relied on their ability to identify different crops and to estimate their health by applying such clues as size, shape, texture and tone and by making full use of corollary information such as soil characteristics, rainfall data, and past history of the agronomy in

25X1 the areas being studied. In [redacted] spectrazonal studies, computer programs were written that assisted in the interpretation of the unique spectral characteristics of various crops within narrow wavelength bands.

2.1.3 As stated above, the photography used in these experimental and practical studies has been of large scale (often as large as 1:1,000) and of correspondingly high ground resolution. As a result, many species of plants could be identified by their shape or texture, by row spacing, and by other relatively small details. Similarly, color photography has been obtained at low altitudes, where atmospheric conditions permit high fidelity color rendition, and color differences could be readily detected.

2.2 HYPERALTITUDE PHOTOGRAPHY

2.2.1 Hyperaltitude photography is the primary, if not the only, source of current intelligence on many denied areas. This photography has been exploited very successfully to produce military and political intelligence. To date, the limitation imposed by scale, resolution, and lack of interpretation techniques has precluded the exploitation of this photography to obtain intelligence on agricultural activity in the denied areas.

2.2.2 Imagery obtained at scales ranging from 1:80,000 to 1:200,000 cannot, of course, provide the photointerpreter with the same degree of detailed information available in large scale photography. The interpreter can no longer rely on such clues as the shape and size of plants to identify or classify crops. However, other clues are available that give promise of providing valuable information. Among these are texture, tone, and spectral response. Certain of these clues are detectable by visual examination of the photography. Others may require the application of relatively sophisticated instrumentation to extract the necessary differentiations. A combination of visual interpretation and instrumental data extraction offers the possibility of highly accurate determination of the identity and condition of agricultural crops.

2.3 PROPOSED TECHNIQUE

2.3.1 It is suggested that, even at the extremely small scales typical of hyperaltitude photography, different crops will exhibit different and unique signatures. These signatures will result from the manner of planting (row crops versus broadcast or groundcover crops), the physical characteristics of the plants themselves (broad leaf versus narrow leaf; low versus high growth), the color of the plants (differences in verdancy between different plants, and between the same plants under different climatic conditions or at different times during the growing cycle), the presence or absence canals or other irrigation facilities, the types of soil suitable for growing specific crops, and other clues. of

2.3.2 It is immediately apparent that an interpreter working with hyper-altitude photography must rely on gross clues. If resolution of the order
25X1 of [redacted] is the best that can be expected, the clues must be discernible at this resolution. Visual inspection of photographs at this resolution should be adequate to differentiate between crop land and fallow or range land, and to permit crop classification in broad terms (small grain, corn, tuberous, leguminous, etc.) Texture created by the manner of planting, shadows, or the characteristics of the plants may be detectable. Many agricultural practices typical of different crops may assist in their identification; these include crop rotation, contouring, fallowing, plowing or other pre-seeding preparation, and mulching and other post-emergence procedures. Although many of these identifiers may be individually small, their appearance in a large area will probably create unique and detectable textural or tonal differences.

2.3.3 In addition to clues revealed by visual inspection of the imagery under high magnification and possibly in stereo, it is highly probable that different crops will exhibit additional signature elements that can be detected only by the analysis of microdensitometric measurements. It is this feature
25X1 that [redacted] suggests as being worthy of further exploration, on the basis of tests made in preparing this proposal. [redacted] has made microdensitometer traces 25X1

of photographs of agricultural areas on medium (1:20,000) and small (1:200,000) scale photographs. The traces exhibit different patterns, density amplitudes, and density levels as the scanning spot moves from one crop to another. Figures 1,2, and 3 illustrate the results of these tests.

2.3.4 The primary purpose of the proposed investigation is to develop methods for estimating the yield of small grain crops. It is necessary, therefore, to establish the characteristics of the images of several different species of crops to determine those that differentiate small grain crops from other crops. Additionally, it is necessary to establish the characteristics of imagery of small grain crops at various times during the growing period, and in varying conditions of health/vigor. Ground data and other corollary information must be acquired at the same time that photography is acquired in order that the results may be analyzed and correlated.

25X1 2.3.5 [redacted] believes that the investigation proposed herein will show that hyperaltitude photographs of extensive agricultural areas contain signatures that will permit the identification of crop species, and the estimation of crop vigor/health and potential yield.

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3. TECHNICAL APPROACH

3.1 INTRODUCTION

25X1 3.1.1 [redacted] proposes to investigate the extension of visual interpretation techniques to the exploitation of hyperaltitude photography for 25X1 agricultural information. In addition, and most important, [redacted] proposes to augment the visual interpretation by the analysis of quantitative microdensitometric measurements of the photography in the expectation that strong correlations can be established that will permit trained interpreters to estimate crop yields with a small percentage of error.

The plan of investigation involves the following:

1. Acquisition of photographs of crops grown under controlled conditions.
2. Laboratory manipulation of the photography to produce imagery simulating that acquired at different altitudes and with different ground resolutions.
3. Visual interpretation of the photography.
4. Microdensitometric measurement of the imagery.
5. Digitization of the densitometric data.
6. Subjection of the digitized data to analysis of variances techniques using computer programs especially written for this purpose.
7. Correlation of the results of the visual interpretation and the computer derived data to establish signatures for different species of plants, different health/vigor conditions, and parameters for estimating crop yield.

3.2 GENERAL PROCEDURE

25X1 3.2.1 [redacted] proposes to go from the known to the unknown. First, photography will be obtained of different crops raised in a controlled environment; ground truth data will be obtained concurrently. This photography will be subjected to the operations outlined in the preceding paragraph. If the results of this phase of the investigation substantiate the feasibility of the proposed treatment, photography will be obtained of crops on which ground data are available, but these data will not be used until the photography has been interpreted visually and analytically. The results

of this "blind" test will then be compared to the ground truth data to further establish the validity of the procedures. Again assuming that
25X1 the proposed techniques are shown to be valid, [redacted] will attempt to extrapolate these techniques to the exploitation of hyperaltitude photography obtained under operational conditions over areas on which ground truth data are available. The interpretative results obtained in this phase will again be correlated with the ground truth data to establish the validity of the extrapolations, or to determine areas in which the techniques are deficient and subject to modification.

3.2.2 The primary objective of this study is to develop a method for predicting the yield of exportable crops. The most important of these are the small grains, and especially wheat. Although it is possible that the techniques proposed herein may enable the interpreter to differ-
25X1 entiate between the small grain species, [redacted] recommends that the scope of the investigation be limited to differentiating small grains from other crops, and to determining methods of predicting the yield of wheat only. Assuming successful results under this limitation, additional research to permit finer crop identification and yield prediction may be undertaken.

3.3 CONTROLLED CROP PLOTS

25X1 3.3.1 After lengthy consideration, [redacted] has concluded that it is not feasible to attempt to use existing photography (such as might be available in the files of the Department of Agriculture) to conduct this investigation. Although it is known that many federal, state, and educational organizations conduct carefully controlled agricultural experimentation and maintain exact and detailed data on such experiments, it is believed that the acquisition of existing photography of crops at such experimental test sites that would satisfy the requirements of this investigation would be difficult, if not impossible.

3.3.2 [redacted] therefore has based this proposal on the assumption that the sponsoring organization can obtain the cooperation of a federal, state, or 25X1
educational agricultural experimentation station in providing target plots. The requirement is for the planting of six plots, each approximately one mile in length and one-fourth mile in width, preferrably in juxtaposition. The crops are to be as follows:

- Plot 1: Wheat, nurtured throughout the growing season by standard agricultural procedures.
- Plot 2: Wheat of the same seed batch, allowed to grow without human attention.
- Plot 3: Wheat of the same seed batch, to be infected by some disease or otherwise damaged at some point or points during the growing cycle.

Plot 4: Corn or sorghum, nurtured by normal procedures.

Plot 5: Beets or soybeans, nurtured by normal procedures.

Plot 6: One half devoted to a mixture of wheat, barley and millet; one half devoted to barley; both to be nurtured by normal procedures.

3.3.3 These plots will be photographed at specific intervals during the growing cycle (see paragraph 3.4 below). At the same time, ground truth data on the conditions in each plot will be acquired. These data will include soil conditions (moisture content, pH, nitrate content, etc.), state of health/vigor of the crop, nature and extent of disease of damaged crops, and estimates of the potential yield of the wheat crops. Additionally, photographs of each crop will be taken from the ground, using the same types of film that are used in the air. The data normally maintained by the agricultural station, including climatological and other general information, will be made available for this investigation. Spectroscopic measurements of the crops at several locations within each plot will be made.

3.3.4 At harvest, the actual yield of each wheat plot will be determined. The predicted yields will be compared to actual yields, and any differences will be analyzed to determine causes and corrective measures.

3.4 PHOTOGRAPHIC SPECIFICATIONS

3.4.1 Photography of the control plots will be made on panchromatic black-and-white film [redacted] through the normally used minus blue filters. A minimum time interval will be allowed between the two types of photography; ideally, they will be made on the same flight and within a 30-minute period.

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25X1

[redacted]

3.4.3 Photography will be obtained at three times during the growing cycle. The first mission will be flown when the crop in Plot 1 is between 1 and $1\frac{1}{2}$ feet in height. The second mission will be approximately one month later, when the crop has attained its maximum height and is beginning to develop its spikes. The third flight will be made just prior to harvesting the crop on Plot 1. Two other flights will acquire supplementary data: a mission just after the crop is planted to record cultivation patterns, and a flight after harvest to provide information that will aid in differentiating between harvested and unharvested fields.

3.4.4 The photography will be degraded in the laboratory to simulate the scale, resolution, and tonal qualities typical of operational hyperaltitude photography. The degradation will be attained by photographically copying the original film at reduced scales; if necessary, the effects of haze will be simulated by degrading the focus or by use of a haze simulation
25X1 technique devised by [redacted] for other experimental work in high-altitude simulation. Degradation will produce imagery with approximate ground
25X1 resolutions of [redacted]

3.4.5 Photography will be accomplished between the hours of 1000 and 1400 in order to coincide approximately with engineering photography obtained at hyperaltitude by operational systems.

3.4.6 Gray scale and color patch targets will be placed at the control plots to permit evaluation of the sensitometry of the processed photography. The data obtained from this control process will be used in correcting the densitometer readings during the computer operations.

3.4.7 It is expected that the feasibility of the procedures proposed herein will be adequately demonstrated in time to permit the acquisition of photography of uncontrolled crops during the month preceding harvest. The area to be photographed will be typified by large areas devoted to wheat and other small grains, with areas of corn and other crops interspersed
25X1 throughout. Both panchromatic [redacted] photography will be obtained on flight lines that will be selected in accordance with crop condition data to be obtained from the Department of Agriculture or other agricultural control agencies. The purpose will be to obtain simulated high altitude photography depicting different species of crops, and especially different health/vigor conditions in the wheat crop. If possible, actual operational photography will be obtained of the same area, at approximately the same time, to provide further corroborative information.

3.4.8 Assuming that the interpretation of the photography obtained as in the preceding paragraph continues to substantiate the feasibility of the proposed techniques, the holdings of the sponsor will be researched to locate hyperaltitude photography of domestic areas devoted to small grain crops. Crop yield data will then be acquired from federal or state agricultural agencies. The hyperaltitude photography will be interpreted in accordance with the proposed techniques, and the results correlated with the actual yield data.

3.5 VISUAL PHOTOINTERPRETATION

3.5.1 Determination of the health/vigor of the crop is of major concern in this investigation, because this factor will be used as the scheme to correlate image-derived data with crop yield. Measurements of soil fertility, knowledge of the type and quantity of fertilizer applied, soil moisture,

pH, and temperature, and other physical elements will not be applicable to the hyperaltitude photography. It is therefore necessary to design a system which will account for such factors, but which will not be directly concerned with recognizing or measuring them.

3.5.2 The visual photointerpretation will be accomplished monocularly and stereoscopically. Various viewing devices will be used, including binocular mirror stereoscopes, zoom stereoscopes, an [redacted] variable magnification rear projection viewer, and a [redacted] stereocomparator. The interpreters will attempt to accomplish the following data extraction:

25X1
25X1

1. Delineation of areas of cultivated ground exhibiting similar textures, similar tones, and similar cultivation patterns.

2. Detection of diseased or damaged crops.

3. Cataloging of differences in appearance between different crops, and between different conditions in the same crop.

4. Cataloging the differences in appearance resulting from degradation of the same imagery.

5. Estimation of the stage of maturity of the crops.

25X1

[redacted]

8. Correlation of the ground photographs with the aerial photographs, and of the spectrometer data with the color film imagery.

9. Detection of agricultural practices associated with crop species.

3.6 MICRODENSITOMETRY

3.6.1 The major premise upon which the proposed technique is based is that analysis of microdensitometric measurements of the imagery will provide data on variations in density that will correlate with differences between crop species, crop health/vigor, and crop maturity, and that these data can be used to predict crop yield. The validity of this premise has been demonstrated in Figures 1,2, and 3. The traces made across different

crops and fields differ in visual appearance, in amplitude, and in average density level. These differences are believed to be repeatable, and to provide visual and analytical clues to the identity and condition of the imaged crops.

25X1 3.6.2 [redacted] microdensitometer will be used to produce the density traces. As illustrated in Figures 1, 2, and 3, different visual appearances result when the X-Y ratio is varied. The scale of the photography also affects visual appearance. Because the visual appearance of the traces is expected to provide a valuable crop identification clue, [redacted] will experimentally determine the optimum combination for producing visually interpretable traces. 25X1

3.6.3 The most important application of the densitometric data will be in the statistical analysis of variances in density as described in paragraph 3.7 below. To provide an adequate quantity of data, at least three traces will be made of the photographs of each plot. Approximately 150 density readings will be made of each trace, using a [redacted] Comparator. The number of readings will be the same for each plot; the X-axis intervals will vary according to the trace. 25X1

25X1 [redacted]

3.7 QUANTITATIVE ANALYSIS

3.7.1 <u>Basic assumptions</u>. The technique described in this proposal is based on the assumptions listed below:

1. Densitometric measurements will exhibit differences attributable to differences in the reflectivity of crop species.

2. Densitometric measurements will exhibit differences attributable to differences in the reflectivity of crops of different health/vigor.

3. Densitometric measurements will exhibit differences attributable to changes in the reflectivity of a crop during its growth cycle.

4. Densitometric measurements will exhibit differences in reflectivity caused by cultivation characteristics.

5. The measured differences resulting from assumptions 1, 2, 3, and 4 are unique.

6. The measured differences resulting from assumtions 1, 2, 3, and 4 will correlate with crop yields.

It is the purpose of the investigation proposed herein to ascertain the validity of these assumptions and, to develop operational techniques and reference materials for the estimation of crop yields from subjective and objective data derived from visual and densitometric interpretative procedures.

3.7.2 The computer program that will be written for this investigation will be designed to extract the densitometric information contained in the sample-to-sample differences for any number of samples, while at the same time suppressing the density-to-density differences that are the same for all samples. The computer-assisted techniques are described below.

3.7.3 Density Matrix. In the quantitative analysis program, the density measurements will become the elements of a matrix:

$$\begin{matrix} D_{11} & D_{12} & D_{13} & \cdots & D_{1j} \\ D_{21} & D_{22} & D_{23} & \cdots & D_{2j} \\ D_{31} & D_{32} & D_{33} & \cdots & D_{3j} \\ \vdots & \vdots & \vdots & & \vdots \\ D_{i1} & D_{i2} & D_{i3} & \cdots & D_{ij} \end{matrix}$$

The matrix represents the density measurements of j objects in i samples. The first row contains the densities for j different measurements in the first sample. Each sucessive row through i contains j measurements of each of the sucessive samples. Comparisons between samples can be made by determining the differences between rows of the matrix. These results may be of any or all possible sample combinations. The positive and/or negative characteristics from sample-to-sample may be investigated.

Results of the sample-to-sample differences will assist in "scrubbing" the data of blunders in density measurements caused by dirt or faultly processing of the film. Differences between samples from variations caused by changes in sun angle or crop moisture

condition may be detected at this point in the analysis. The effective range of the density scale between samples is indicated.

3.7.4 Density Deviation Matrix. Since the sample densities measured from the photo image are relative to one another rather than absolute, the density matrix is used to create a deviation matrix. For each sample (matrix row) the average is computed and subtracted from each measured density (object).

$$DV_{ij} = D_{ij} - \frac{1}{n}\sum_{j=1}^{n} D_{ij}$$

Positive and negative values will occur in the deviation matrix and the sum of the values will equal zero. The difference between any two values in a sample (row) still has the same value as the difference between corresponding elements in the density matrix.

3.7.5 Variance, Covariance, and Correlation. The variability among the elements of a sample (row) in the deviation matrix furnishes an indication of the information recorded in that sample with respect to the image interrogated. The mean sum of the squares of the deviation matrix the sum of squares is computed by:

$$S_i^2 = \sum_{j=1}^{n} DV_{ij}^2$$

and the variance by,

$$\sigma_i^2 = \frac{1}{n}\sum_{j=1}^{n} DV^2{}_{ij}$$

It is anticipated that densities of one sample will correlate highly with densities from another sample in the same category (example, vigorous/healthy grain plot). The (product-moment) correlation coefficient (R) between two samples (rows) is computed by,

$$COV_{im} = \frac{1}{n}\sum_{j=1}^{n} DV_{ij}\ DV_{mj}$$

$$R_{im} = \frac{COV_{im}}{(\Sigma\ DV_{ij}\ \Sigma\ DV_{mj})^{\frac{1}{2}}}$$

If two samples (rows) are perfectly correlated, the correlation coefficient is unity. The correlation between samples is Weaker ~~easier~~ as the coefficient becomes less than unity. A strong correlation indicates the similarity of measurements between samples. A correlation significantly less than one indicates that the measurement to measurement densities are greatly different.

The anticipated correlations for the small grain crops at the test control site are as follows:

1. A strong correlation between sample data within the grain species. The strongest correlations will be in the healthy/vigorous plots and less strong in the stunted.

2. A weak correlation between sample data of between-species groups. Health/vigor crop characteristics are anticipated to have little effect.

3. It is further anticipated that strong correlation of the within species samples will be evidenced in data samples from the first and second flights.

4. For data samples from the third flight, the expected result is a general weakening of all previously strong correlations.

The correlation coefficient has an added significance. If its value is squared (R^2), it is a measure of the fraction of the variance of one sample (row) which can be predicted, based upon the variability of another sample(row). ($1-R^2$) gives a measure of the fraction of the variance in each sample(row) not accounted by the other.

3.7.6 Control Test Evaluation. After each of the photographic missions has been flown and the data have been reduced to density graphs, density matrix sample differences, and variance and correlation coefficients, an evaluation of the effectiveness of the interpretative procedure must be made. First, the differences exhibited between density matrix samples must be significant between crop species. The greater these differences the more successful the interpretation. Second, note must be made of all correlation coefficients near unity; these should be the within-species coefficients. Slightly less strong correlations should occur within the species as based upon lack of vigor. Third, for all of the significant correlations identified, it should be determined how much of the variance for each sample may be predicted. Fourth, the results of the test must be consistent from mission to mission. Consistency of the results determines the measure of success achieved.

3.7.7 As described above, the original photography of the control plots will be degraded to produce imagery at different ground resolutions. For each set of imagery, densitometer readings will be made and subjected to the procedure described above. The resulting correlation coefficients will represent correlations between the control site measurements on the original photography and the measurements on the first degraded imagery. Subsequently derived coefficients will be between successive degradation steps. At some point, if this procedure is carried out sufficiently far, a correlation will cease to exist. However, when the final correlation is made between degradation steps, a coefficient will be computed between the final step and the control test measurements. At this point, it will be possible to determine how much of the predicted control test statistical variance is lost when predicting the degraded step variance. It is expected that the prediction ($1-R^2$) will remain above Below 50% of σ^2 for those samples.

3.8 CROP YIELD PREDICTION

3.8.1 During the test period, crop yields from the control plots will not be known until after the photographic data have been reduced. Therefore estimates of the yield from plots 1,2,3, and 6 will be made by the agricultural station or agent responsible for the control test site. Estimates will be made at the time of each photographic mission. The accuracy of these on-site predictions (as compared to actual yield at harvest) will give insight into what may be expected from the photographic assessments. The grain yield data from the test site will provide only one yield per-acre figure for each species plot. This is inadequate for establishing yield levels to be incorporated into a predictive scheme. Supplementary yield data are a requisite.

3.8.2 These supplemental data will be acquired by photographing uncontrolled crops (see paragraph 3.4.8 above) and making on-site estimates of crop health/vigor and potential yield concurrently with the photography. The imagery will be treated in the same manner as that from the controlled plots, and the results will be evaluated to establish correspondence with earlier experimental data. A sufficient number of samplings will be made to assure statistical accuracy. Density curves and correlation coefficients will be established between these supplemental data and the control test data. The acutal yield of the photographed areas will be determined at harvest; actual yield figures will be compared to estimated yield figures obtained at the time of photography, and techniques will be developed for converting photointerpretative and variation analysis data to crop yield predictions.

3.8.3 Final validation of the techniques for crop yield prediction will be made by applying them to actual hyperaltitude photography. It is proposed that the files of domestic photography held by the sponsor will be researched to identify frames that include photography of wheat crops at the three times specified in paragraph 3.4.3 (at a crop height of about 1 - 1½ feet, at the time when the crop has achieved its maximum height and is beginning to spike, and immediately before harvest). This photography will be interpreted as described above. Actual yield figures will be obtained and compared with the predicted yield figures derived from each set of photography. The correlation between predicted and actual yield figures will validate the proposed techniques, and/or will suggest modifications and adjustments that will permit their use for the intended purpose.

3.9 PREDICITIVE TECHNIQUES

3.9.1 The quantitative analysis procedures described above will generate numerical values that will represent the nature and degree of similarities and differences between reflectivities of different crop species, different health/vigor conditions, and different states of maturity. These values, in conjunction with visual photointerpretative data, are expected to prove the validity of the assumptions made in paragraph 3.7.1.

25X1 3.9.2 In its final report, [redacted] will describe the methods by which small grain crops can be differentiated from other crops, and by which the yield of the small grain crops can be estimated at various times during the growing cycle. The report will include reproductions of imagery acquired during the investigation and of microdensitometer traces made from the imagery. It will also include documentation on the computer programs that will be developed for the analysis of variations and the numerical data derived by operation of the programs.

4. STATEMENT OF WORK

25X1 [redacted] Corporation will supply the necessary personnel, facilities, services, and materials to accomplish the following tasks.

Task 1. Arrange for the establishment and maintenance of control crop plots.

Task 2. Acquire aerial photography of the control plots and of uncontrolled crops. Degrade the photography to simulate hyperaltitude photography.

Task 3. Perform visual interpretation of the photography and report on information pertaining to crop identification and the estimation of crop health/vigor and potential yield.

Task 4. Make microdensitometer traces of the photography. Convert the densitometer traces to digital data.

Task 5. Prepare computer programs for analyzing the variations in density represented by the numerical values derived in Task 4.

Task 6. Compute correlation coefficients and other numerical values.

Task 7. Analyse the photointerpretative and quantitative data to establish methodology for identifying crop species and for estimating crop health/vigor, maturity, and potential yield of small grain crops.

Task 8. Prepare a report describing the investigation and the methodology developed in Task 7.

The investigation will require approximately nine calendar months. It is anticipated that Task 1 will be initiated in March 1967. The remaining tasks will be accomplished as photography of the control plots is acquired; it is estimated that the photo missions will be flown in the period May - August 1967.

FIGURE 1

The scale of the photo negative from which these densitometer traces were made is 1:5,000. Points A, B, C, and D as indicated on the enlarged photo correspond to the same points respectively along the traces as represented in Figures 1.2, 1.3, 1.4, 1.5, and 1.6. A change in the ratio of the density trace represents an exaggeration in the X direction. This expands the length of the trace; the magnitude of the gray scale (Y direction) is not affected by a ratio change.

Figure 1.2. This trace illustrates density patterns, amplitudes, and levels derived from the imagery of three different crops.

Figure 1.3. Represents a ratio of 1:10 between the photo negative and the density trace. It indicates a step in the scale exaggeration, and provides more detailed density information than the corresponding portion of Figure 1.2.

Figures 1.4, 1.5, and 1.6. Represent a ratio of 1:20 between the photo negative and the density trace. They indicate more clearly the density differences and allow digitalization of the density measurements.

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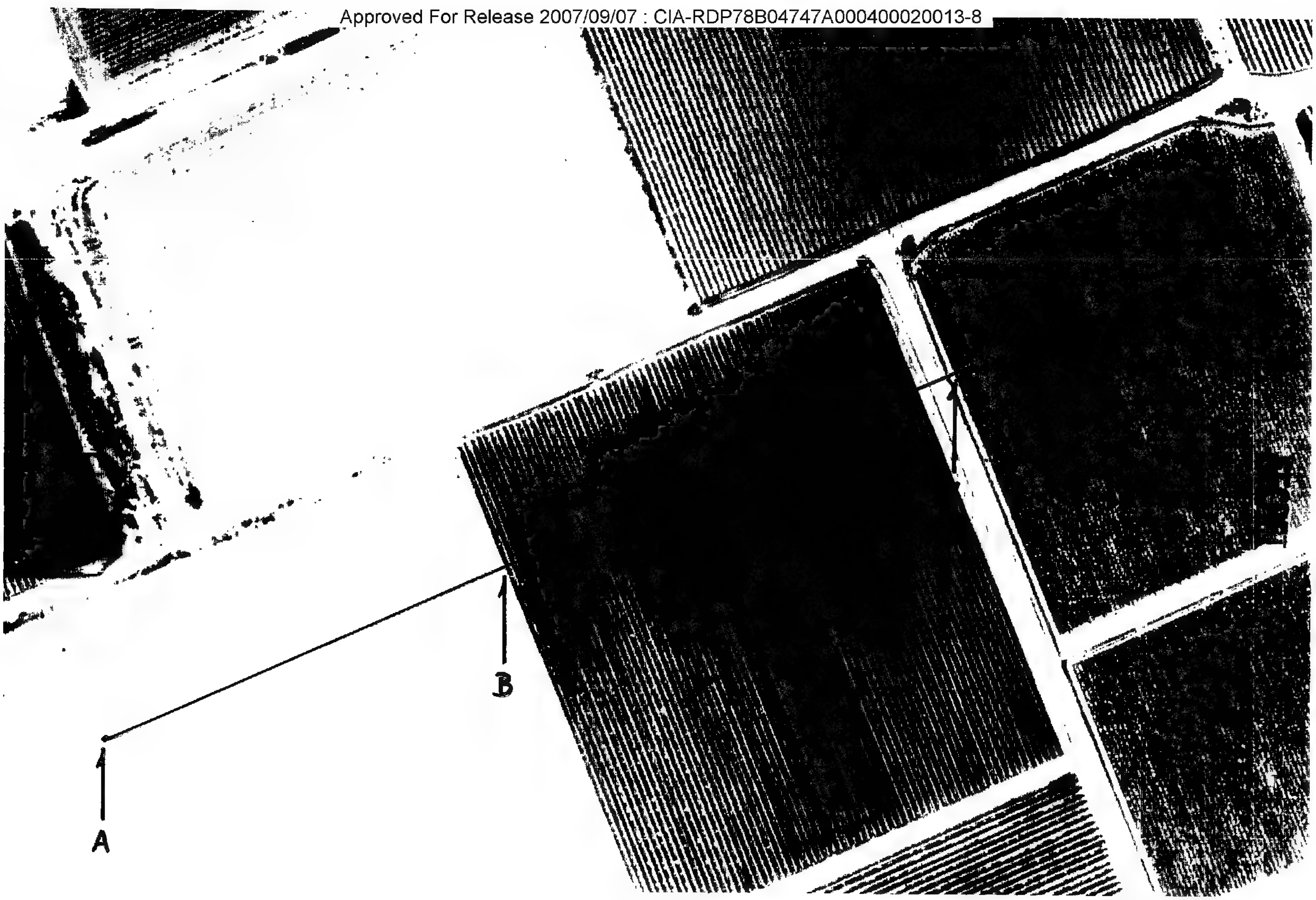

FIGURE 1.1

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FILM: B&W PANCHROMATIC
RATIO: 1:5

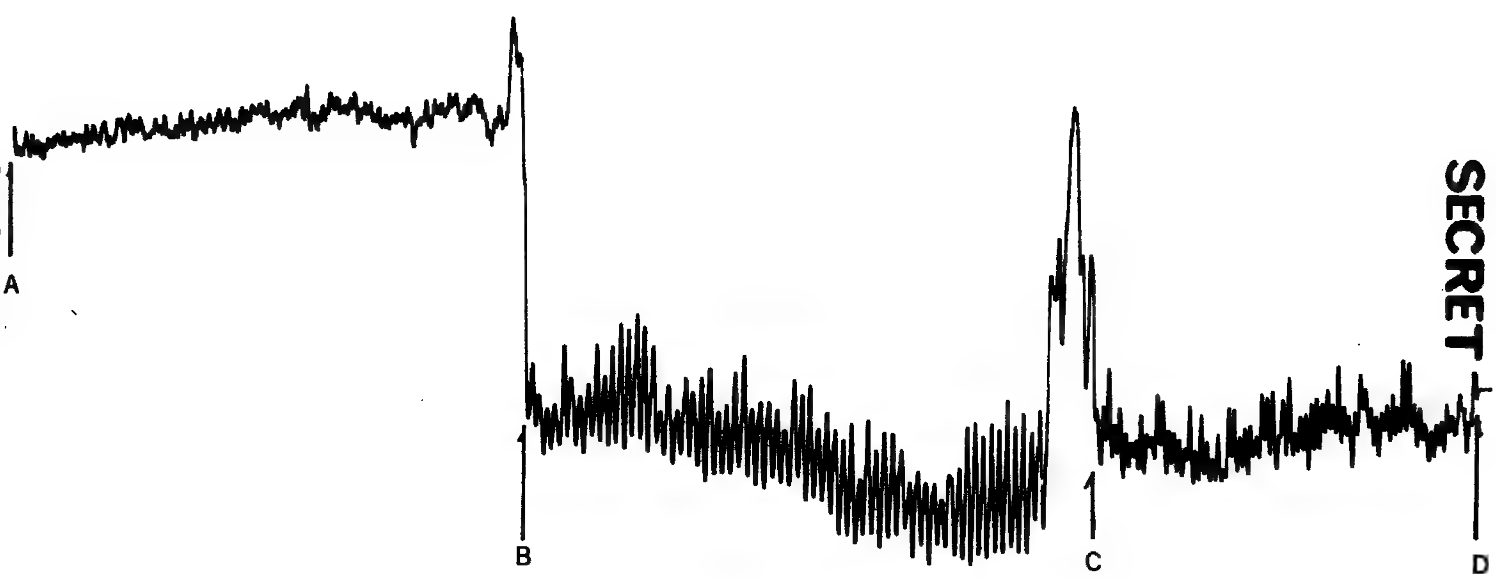

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FIGURE 1.2

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FILM: B&W PANCHROMATIC
RATIO: 1:10

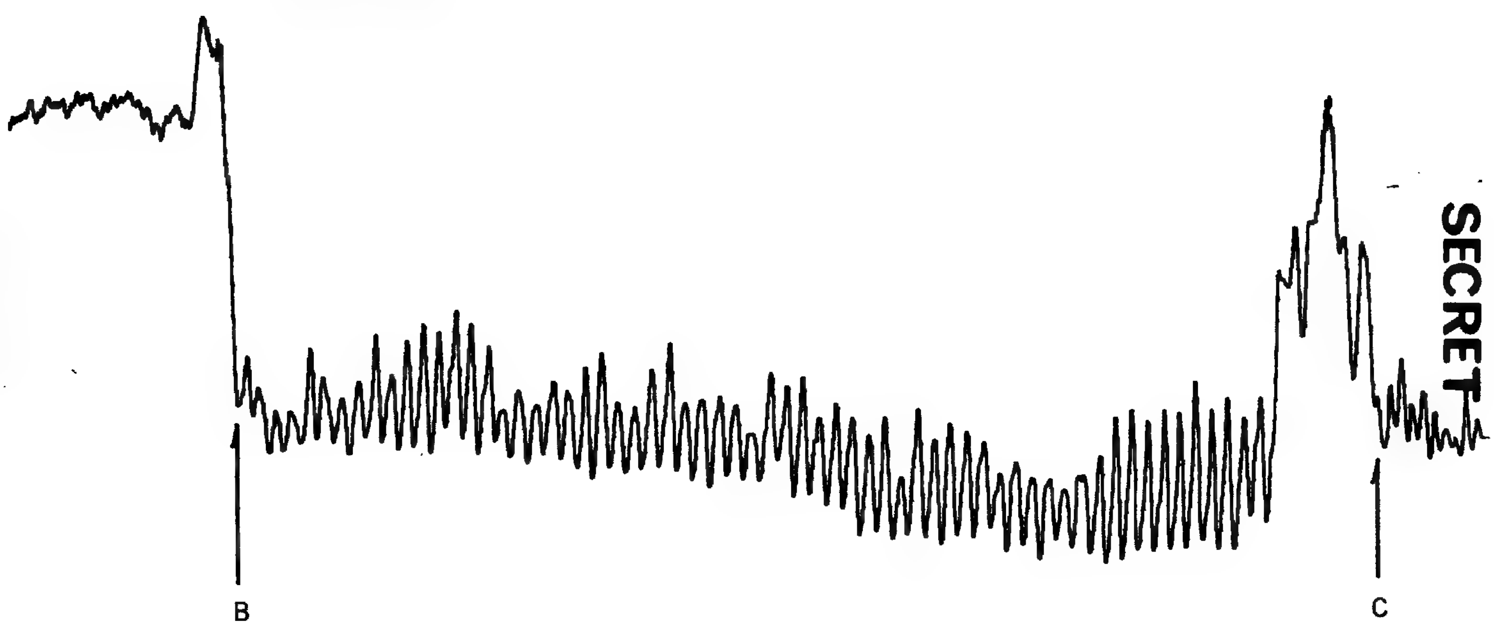

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FIGURE 1.3

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FILM: B&W PANCHROMATIC
RATIO: 1:20

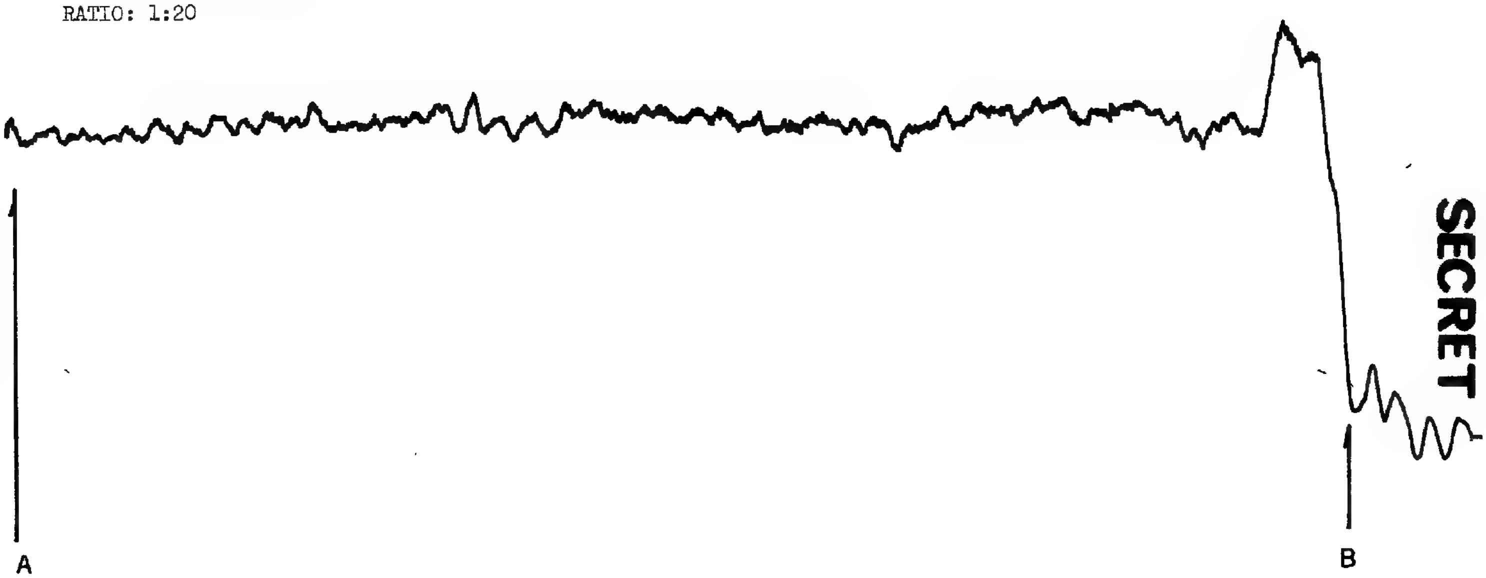

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FIGURE 1.4

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FILM: B&W PANCHROMATIC
RATIO: 1:20

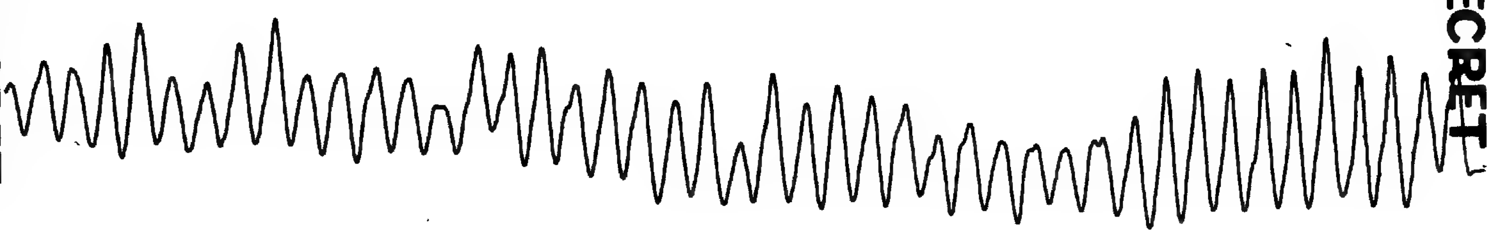

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FIGURE 1.5

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FILM: B&W PANCHROMATIC
RATIO: 1:20

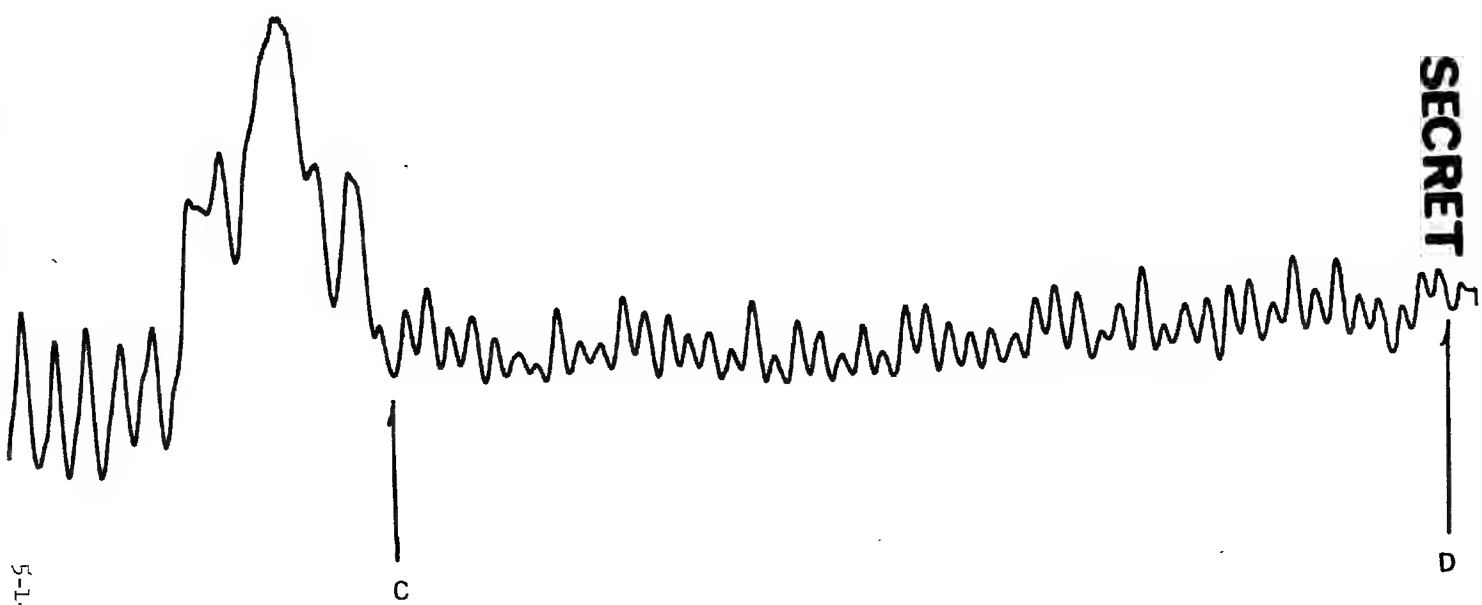

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FIGURE 1.6

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FIGURE 2

The scale of the photo negative from which these densitometer traces were made is approximately 1:150,000. Points A, B, C, D, E, and F as indicated on the enlarged photo represent the same points respectively on the trace.

Figure 2.2. Expresses a ratio of 1:4 between the photo sample and the density trace. The trace illustrates clearly those fields which are similar, the abrupt changes caused by field boundaries, streams and slopes.

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FIGURE 2.1

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FILM: B&W PANCHROMATIC
RATIO: 1:4

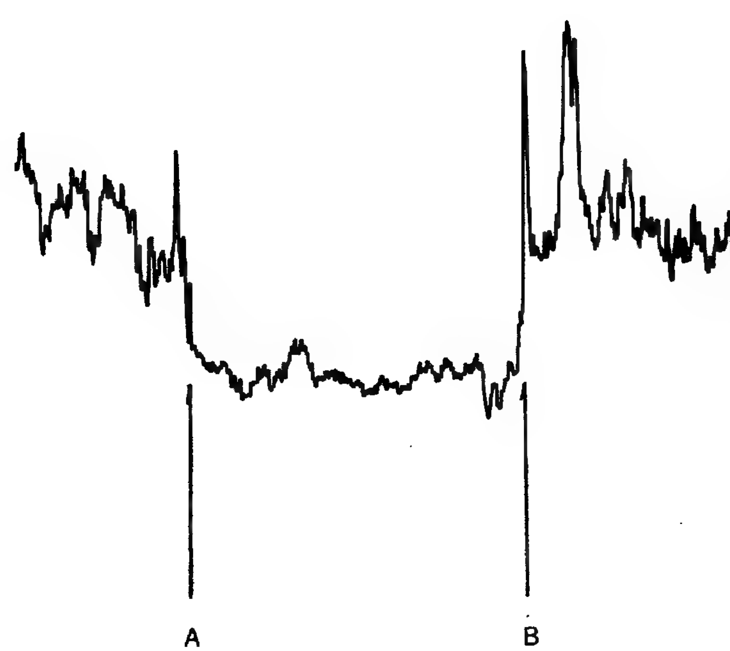

FIGURE 2.2

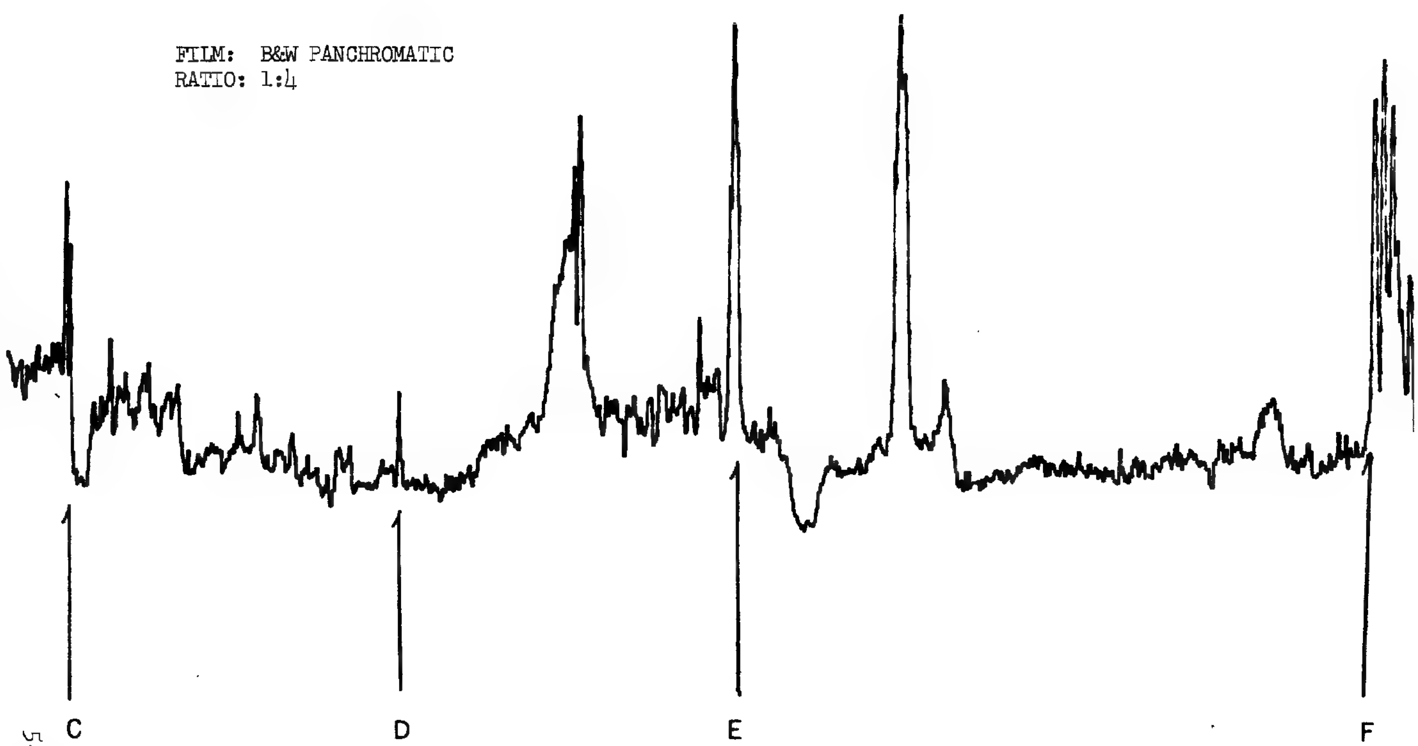

FIGURE 2.2 (con't)

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RELATED EXPERIENCE

25X1

[redacted] organization. Under the terms of its charter, the center offers contract services based on special capabilities in photogrammetry, geodesy, remote sensor record analysis, photointerpretation, and photographic reproduction. Specifically, the center is manned and equipped to provide services and products based on the following:

> Analysis and interpretation of photographic and other remote reconnaissance sensor records. Development and improvement of data extraction and handling techniques. Preparation of specifications for the design of image analysis and interpretation equipment.
>
> Analysis of photogrammetric and geodetic problems inherent in the exploration of the earth, the moon, and the planets from various types of platforms. Performing systems analysis to develop specific analytical solutions and equipment performance specifications. Testing of such solutions and equipments.
>
> 25X1 Calibration and testing of [redacted] manufactured photogrammetric and photointerpretation equipment and technology.

frame photography obtained simultaneously, with emphasis on cartographic applications.

Calibration and operational testing of [redacted] produced panoramic rectifying printers. 25X1

25X1 [redacted] formed in 1957 in response to critical needs for advancing the state of the art in information technology. In meeting its extensive contractual obligations to the Government, industry, and the military, [redacted] has made substantial contributions to the fulfillment of national needs, and has established itself as a leader in the country's photo-optical and information handling industry.

25X1

25X1 [redacted] Center is a part, is primarily engaged in design and development programs for both military and nonmilitary customers. The scientists and engineers of this group work as project teams, and apply their knowledge of many scientific and engineering disciplines to the expeditious and economic solution of systems and equipment design problems.

25X1 [redacted] personnel were responsible for the first successful panoramic photography from the air and, since that time, the majority of programs undertaken by the group have been directed toward the development of photographic systems and their related ground handling equipments.

25X1 [redacted] broad background in the field of information technology includes such major advances as:

Development of the world's largest photographic lenses and cameras

First concept and design of television viewfinders for pilots

Pioneering in the application of information theory to optical systems

First accurate tracking of a manmade satellite (Sputnik)

Research into human factors relating to photointerpretation; design and construction of advanced photointerpretation viewing devices

Development of optical electronic image enhancement techniques

Development of photographic rectifying printers for panoramic photos

Integration of multisensor equipment in advanced reconnaissance systems

25X1 [redacted] occupies over 1 million square feet of floor space at locations throughout the country. These facilities are devoted to the company's engineering, research, fabrication, marketing, and administrative operations. Net sales and income from contracts exceeded [redacted] 25X1

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EXPERIENCE

During its first two years of operation, the [redacted] 25X1
participated in a wide variety of projects involving the application of scientific, engineering, and technical skills in the general area of exploiting the data contained in remote sensor systems. Most of these projects have been direct or indirect contributions to
25X1 [redacted] work on Government contracts; some have been in-house efforts aimed at increasing the capabilities of [redacted] and of the 25X1
25X1 [redacted] in specific technical and scientific areas.
The following pages briefly describe some of the major projects undertaken by the Center since its establishment.

EXPERIENCE

1. In cooperation with U. S. Army GIMRADA and the American Society of Photogrammetry, an analysis of the comparative value of panchromatic, conventional color [redacted] 25X1 aerial photography for the interpretation of vegetation, soil types, cultural features, and drainage.

2. Under contract with the National Park Service, Department of the Interior, an investigation into the optimum film-filter combination, photographic scale, and interpretation techniques for archeological exploration by aerial photographic reconnaissance.

3. Under contract with a Department of Defense agency, a study of the photographic parameters for an optimum target system for tactical aerial reconnaissance.

4. As a sub-contractor on a Government contract, a study of the present and future state-of-the-science in aerial color and spectrazonal photography as an intelligence collection system, and of techniques and equipment required to exploit the imagery from such systems.

5. Under contract to a Government agency, studies of the relationships between panoramic and frame photography obtained simultaneously, with emphasis on cartographic applications.

6. Under contract to the Defense Intelligence Agency, compilation of a glossary of terms used in mapping, charting, and geodesy.

7. Participation in a study performed by [redacted] under a Government contract on the feasibility and design of a survivable reconnaissance data processing facility. 25X1

8. As a company-sponsored effort, experimentation and investigation into methods of detecting, identifying, and determining the extent of water pollution and sources of pollution by interpretation of photography obtained with various film-filter combinations.

9. Under contract to a Government agency, performance of an engineering
25X1 test and evaluation of an [redacted] produced rectifying printer.

10. Under various Government contracts, and in support of [redacted] 25X1 engineering and design staffs, participation in and contributions to the design of photo-optical systems produced or proposed by the company, with emphasis on the incorporation of optical and geometric parameters to assure the utility of the imagery in satisfying various reconnaissance and cartographic requirements.

11. Under a Government contract, the development of a mathematical model and associated data processing programs for an advanced reconnaissance-mapping system.

12. Under contract to a Government agency, the provision of consultant services in an evaluation of the utility of certain orbital mechanics computer programs.

13. As a speculative effort, development of a training course to assist a Government agency in overcoming a serious shortage of image interpreters.

14. Under various Government contracts, operation of precision mensuration equipment to calibrate and provide error compensation data for [redacted] produced photo-optical systems.

25X1

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PERSONNEL

A major asset of the [redacted] is the unique qualifications of the scientists, engineers, and technicians who compose the staff. These people have been selected because of their special qualifications in the military and civilian uses of aerial and space photography for intelligence, cartographic, and commercial purposes. Management plans for the Center call for a steady increase in the number of employees to a total of 100 or more. Candidates for employment are carefully screened to assure that they meet the Center's high standards of professional competency and integrity. Many of the staff possess advanced degrees in disciplines germane to the Center's operations; many are former military officers and enlisted men with long years of experience in the acquisition and exploitation of remote sensor imagery for intelligence and cartographic purposes. The Center is certified at the SECRET level; many of the employees have been cleared at higher levels.

Brief biographies of key staff members are presented in the following pages.

EQUIPMENT

25X1 [redacted] STK-1 Stereocomparator

880 Monocomparators

Image Plane Digitizer

IBM 526 Key Punches on-line to the above

25X1 [redacted] Multi-width Variable Magnification Rear Projection Viewer

25X1 [redacted] GFL-940 MCE Light Tables

Zoom 70 Stereomicroscopes

Mirror Stereoscopes with Stereometer

Microdensitometer

Compensating Polar Planimeter

Quantalog Color Densitometer Model F-10

Densichron

V-184 10 x 10 Projection Printer

Holzworth 10 x 20 Contact Printer

Transflow Continuous Film Processor

Platemaster and Lithographic Press

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25X1

MEMORANDUM FOR: [redacted]

This staff appears to be devoid of a ? qualified PI. [redacted]

25X1

m

7 Mar
(DATE)

FORM NO. 101 REPLACES FORM 10-101 (47)
1 AUG 54 WHICH MAY BE USED.

25X1 [redacted]

Frank — TR

25X1

I am having [redacted] and

25X1

[redacted] (technical [redacted] program manager Crop Yield)

25X1

come over here Wednesday morning at 9 AM.

to discuss Technical details.

Jim H

4.1 Project Management

This proposed study program will be under the cognizance of the [redacted] 25X1

25X1 25X1 [redacted] If favorably considered by the Government, the contract would receive recognition by division and corporate management as well as the full support of appropriate operating elements of the company

Successful completion of a program such as proposed here requires a complete understanding of the problem and a management concept which is sensitive to the progress of the program from the standpoint of the fiscal schedule and calender time point of view as well as technical accomplishments, while being responsive to guidance provided by the Contracting Officers technical representative.

25X1 [redacted] has, from its inception, employed a strong program manager concept. Upon the award of a contract, a project manager is assigned. Dependent upon the size and scope of the task, technical and administrative personnel as well as security and other support personnel are assigned. In the case of smaller tasks, a program manager is assigned and support is provided as required. In either of the two instances, the assigned manager has full responsibility and is provided complete access to that level of management required to resolve problems in an effective and timely manner.

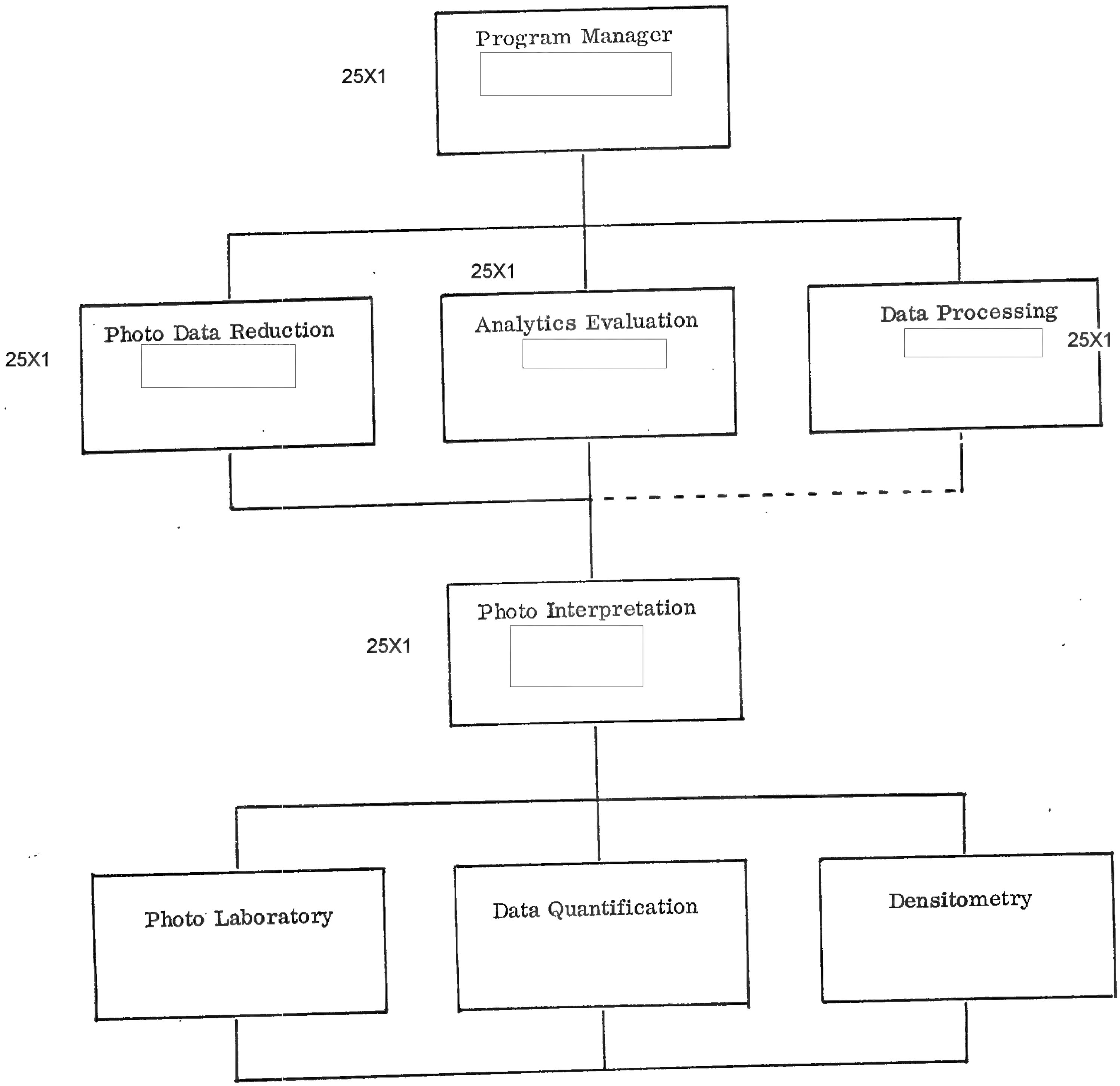
25X1 [redacted] of the [redacted] staff will be assigned as program manager of this contract. Other key personnel that will be involved throughout the proposed study are [redacted] 25X1 25X1

The program management and principal contributors to this program are listed below:

Contributor	Hours	Percent of total program
25X1 [redacted]	1000	18
	350	6
	150	3
	500	9
	500	9
	500	9

A functional diagram of the proposed project team is presented on the following page.

PROGRAM MANAGEMENT



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March 14, 1967

25X1

Plans and Development Staff
1st & M Streets S. E.
Washington, D. C.

Dear Jim:

The enclosures submitted herein are in response to your request at our meeting of March 8, 1967, and your subsequent request by telephone on March 10, 1967. These materials cover the four basic subjects, namely:

1. Photography Acquisition
2. Agronomy Consultant
3. Test Control Site
4. Elucidation of Photographic Degradation Process.

Sincerely,

25X1

Manager, Technical Operations

DKM:lsp

Enclosures

ENCLOSURE 1

<u>Acquisition of Photography</u>

25X1 The [redacted] has a close working relationship with the [redacted] 25X1

25X1 [redacted] coordinates our respective requirements.

Contractural arrangements of long standing with [redacted] permit 25X1 the utilization of their aircraft, crews and cameras. It is our intent

25X1 to employ [redacted] aerial cameras for the acquisition of photography.

ENCLOSURE 2

Agronomy Consultant

Based upon the project requirements, the need for a consultant to ensure the timely and accurate recording of ground data at the control area site is evident.

The consultant tentatively engaged:

25X1 [redacted]

25X1 [redacted]

Experimental Stations ensures the cooperation of the entire organization. Assistance in gathering soil moisture readings and yield estimates throughout the program, and in placing the color and grey scale targets will be assured.

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ENCLOSURE 4

Photographic Degradation Procedures

As stated in the proposal, the original photography will be flown at 5,000 feet and result in 1:10,000 scale imagery with approximately one foot ground resolution. This photography will be further reduced to approximate 1:50,000 scale with five foot ground resolution and 1:100,000 scale with 10 foot ground resolution. Defocussing techniques may be used if warranted.

If after discussions with the sponsor, haze is considered to be a significant problem warranting further analysis, atmospheric attenuation will be simulatedby procedures developed by [redacted] This 25X1
phase of the work will be under the direction of [redacted] 25X1
The attenuation of light through a neutral density filter will result in the approximate atmospheric simulation.

There is no absolute certainty that the laboratory atmospheric simulation will result in completely satisfactory approximations of operational conditions. Therefore, as stated in the proposal, the sponsor's files should be searched to find examples of the same or similar areas of coverage to compare the degraded with the operational imagery.

Enclosure 5 briefly discusses the problem of atmospheric simulation.

ENCLOSURE 5

Atmospheric Simulation

Considerable thought has been given to the laboratory manipulation of the photography in order to simulate the appearance of the ground scene from above the atmosphere. The atmosphere surrounding the earth presents a problem since it has a distorting effect on tone reproduction. This distortion takes three main forms: (1) a reduction in the overall contrast of the scene, (2) a geometric deformation caused by imaging through a nonhomogeneous medium, and (3) a blue veiling of concern in color photography. For high altitude vertical photography, contrast reduction is the more serious.

A clean atmosphere is composed largely of nitrogen and oxygen gas molecules, with trace amounts of several other gases. These molecules are much smaller than the mean wavelength of visible light. An atmosphere composed only of gas molecules is termed a "Rayleigh" atmosphere.

The real atmosphere also contains larger particles whose size may approximate or exceed the wavelength of light; e.g., water particles, dust, smoke, industrial byproducts, pollen and similar

aerosols. These particles are called "Mie particles", and an atmosphere containing them is termed a "Mie atmosphere." The majority of Mie particles are restricted to the lower regions of the atmosphere (below 15,000 feet), and a predominantly Rayleigh atmosphere exists above this level. For photographic purposes, the effective scattering atmosphere ends at approximately 30,000 feet. Although some dust layers have been noted above this altitude, their contribution to the scattering of light appear to be negligible.

No attempt is to be made to directly simulate actual atmospheric haze. Instead, the optical effects produced by haze on lighting and tone reproduction are to be simulated. Atmospheric haze has three effects to be considered here; (1) the downward scattering of light, (2) the attenuation of light through transmission losses, and (3) the upward scattering of light.

These three effects combine to give an apparent aerial contrast C_a of a ground scene as viewed from above the atmosphere. This can be expressed as

$$C_a = \frac{B_h T_a + B_a}{B_l T_a + B_a}$$

where B_h = highlight brightness of the scene

B_l = lowlight brightness of the scene

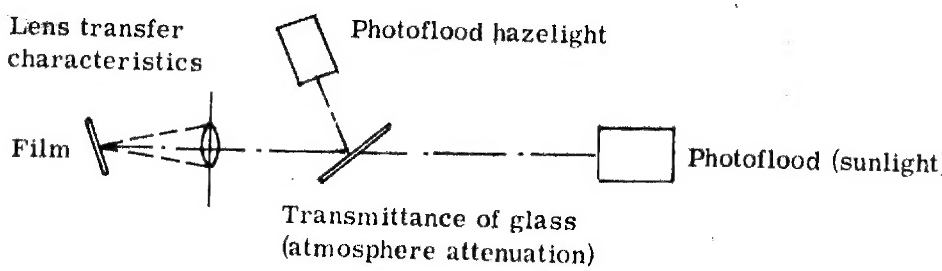
T_a = atmospheric transmission

B_a = atmospheric brightness

The downward scattering of light by particles in the atmosphere increases the amount of light received in the shadowed areas, thereby increasing the shadow detail visibility, but at the same time reducing the ground scene contrast (sun to shadow illumination ratio). Variation and manipulation of the illumination system, in the photographic degradation process, should provide for any desired variation of this ratio by altering the intensity of the sunlight and the skylight.

The upward scattering of light into the camera has an effect equivalent to uniformly fogging the film. Contrast is lowered and the visibility of shadow detail is reduced. This effect is simulated by making the exposure through a uniformly illuminated beam splitter. The illumination is controlled so that a wide range of haze levels can be simulated.

The attenuation of light through transmission losses can be simulated by exposing the positive through a neutral density pfilter placed ahead of the beam splitter. A diagram of a device for accomplishing this is shown on the following page.



Setup for laboratory correlation studies

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